Australian Government

Department of Defence

Defence Science and
Technology Organisation

Body Size Changes of Royal Australian Air Force Aircrew: 1971 – 2005

Grant Tomkinson*, Adam Clark* and Peter Blanchonette

Air Operations Division
Defence Science and Technology Organisation

* University of South Australia

ABSTRACT

The aim of this study was to quantify the secular changes in body dimensions of Royal Australian Air Force (RAAF) aircrew between 1971 and 2005. Small secular increases were observed for most body dimensions, including height, mass and body mass indices, although a small decline was observed for head girth. These secular changes (except for head girth) were not independent of changes in overall body size. In addition, secular changes were not always uniform across the distribution. Secular increases in body dimensions of RAAF aircrew have implications for health, clothing design and sizing, and human-equipment fit.

RELEASE LIMITATION

Approved for public release

Body Size Changes of Royal Australian Air Force Aircrew: 1971 - 2005

Executive Summary

There have been numerous reports of increasing body size in children, adolescents and adults from many countries over the last 150 years. Although the underlying causal mechanisms are unclear, it is generally believed that secular increases in body size are due to improved environmental conditions, nutrition and health care, which has in turn lead to the elimination of growth-inhibiting factors. Secular changes in the body size of military populations have also been documented. Most of the available secular data have been reported on Army personnel, especially the United Kingdom and United States.

The aim of this study was to quantify the secular changes in body dimensions of Royal Australian Air Force (RAAF) aircrew. RAAF aircrew were anthropometrically surveyed twice, in 1971 and 2005. In 1971, 482 male aircrew aged 17–55 years were measured. In 2005, 255 RAAF aircrew (9 females and 246 males) aged 19–56 years were measured. The secular changes over 34 years were assessed by quantifying the magnitude and direction of secular changes in mean values, and by examining changes in the population distributional characteristics, to determine whether changes in mean values were typical or atypical of the rest of the distribution.

There has been a small secular increase in several absolute and proportional body dimensions of male RAAF aircrew over the period 1971–2005, although these increases were not independent of overall changes in body size. However, there was a small secular change in head girth that was independent of overall body size. Furthermore, secular changes were not always uniform across the distribution. These secular changes in body dimensions have implications for health, clothing design and sizing, and human-equipment fit and underscores the need for regular anthropometric surveys of RAAF aircrew. To ensure data is available on the size of current aircrew the Institute of Aviation Medicine will measure aircrew on a regular basis.

Authors

Grant Tomkinson
University of South Australia

Dr Tomkinson was awarded a PhD in Human Movement at the Univerity of South Australia in 2004 and is a Senior Lecturer in the School of Health Sciences at the University of South Australia. He has published 11 peer-reviewed scientific papers, one book and 10 peer-reviewed book chapters since 2003. His main research areas are in pediatric fitness and anthropometry. He has been involved in several large scale 3D anthropometry surveys, including the Australian Defence Anthropometric Personnel Testing project, which measured over 1,800 aircrew and general population, and a recent survey of over 750 athletes at the 2007 and 2008 Australian Rowing Championships.

_____ _____

Adam Clark
University of South Australia

Adam Clark joined the Royal Australian Air Force in 1999 as an Air Traffic Controller. He has spent time on posting and deployment in Darwin (1999 – 2003), Edinburgh (2004 – 2008) and Bagdad International Airport (2004). Adam completed his Physiotherapy Degree in 2008 at the University of South Australia. Adam currently works as a physiotherapist at the Royal Adelaide Hospital in acute care and surgery.

_____ _____

Peter Blanchonette
Air Operations Division

Peter Blanchonette is a S&T 6 in Air Operations Division. He joined DSTO in 1995 after completing a PhD in Applied Mathematics at Monash University. During his time at DSTO Peter has worked in a diverse range of areas including anthropometry, human system integration, helmet mounted displays, ergonomics and operations research.

_____ _____

Contents

1. Introduction

There have been numerous reports of increasing body size in children, adolescents and adults from many countries over the last 150 years (Cole, 2000; Hauspie et al., 1997; Roche, 1979). Although the underlying causal mechanisms are unclear, it is generally believed that secular increases in body size are due to improved environmental conditions, nutrition and health care, which has in turn, lead to the elimination of growth-inhibiting factors (Malina, 1979; Van Wieringen, 1986). Secular changes in body size are best documented for height, mass and mass-for-height indices (Cole, 2000; Hauspie et al., 1997; Roche, 1979). While much of the information on secular changes in body size has been reported on children and adolescents, available secular data on adults (primarily from studies of adults from developed countries) suggest that: (a) adult height has increased in many countries over the past 150 years, and although the secular increase in height is continuing, it appears to have slowed (and stabilised in some countries) since the mid-1970s; and (b) adult mass and mass-for-height indices (often used as proxies of fatness) have also continued to increase, and in many countries, have accelerated in recent decades (Cole 2000; Hauspie 1997; Roche, 1979). It is important to note that these secular changes are not universal. Furthermore, secular data for other body dimensions (e.g. limb and trunk girths, and segment lengths, breadths and heights) are limited.

Secular changes in the body size of military populations have also been documented (Greiner & Gordon, 1992; Knapik et al., 2006; Sharp et al., 2002). Most of the available secular data have been reported on Army personnel, especially the United Kingdom and United States. To date, there has only been one published report on secular changes in body dimensions of Australian military personnel. Using data on 5,643 soldiers from World War I, World War II, the Vietnam War and the regular army service, Soar (1999) reported a 0.41 cm per decade increase in height of soldiers born between 1854 and 1962. Unfortunately, these secular data are out-dated and are only available for the height of Australian Army personnel. It is therefore not known whether the secular increase in height has continued, stabilised or reversed, or whether a similar pattern of change has been observed in other body dimensions or in other Australian military populations. The aim of this study is to quantify the secular changes in body dimensions of Royal Australian Air Force (RAAF) aircrew. This will be achieved by quantifying the magnitude and direction of secular changes in mean values, and by examining secular changes in the population distributional characteristics, to determine whether changes in mean values are typical or atypical of the rest of the distribution. An understanding of the secular changes in body size of RAAF aircrew can help inform the acquisition and upgrade of aircraft, and the design and sizing of clothing and protective equipment.

2. Method

2.1 Anthropometric Surveys

RAAF aircrew have been anthropometrically surveyed twice, in 1971-72 (Hendy, 1976) and 2004–05 (data gathered as part of Australian Defence Anthropometry Personnel Testing (ADAPT) project, unpublished data]. For convenience, the Hendy (1976) and ADAPT (unpublished data) studies will be henceforth referred to as the "1971" and "2005" studies, respectively.

2.1.1 1971 Survey

In the 1971 study, 482 male RAAF aircrew aged 17-55 years were measured as part of a large RAAF anthropometric survey (Hendy, 1976). Aircrew, not stratified by age, rank or experience, were sampled from six RAAF bases (the names of the bases were not reported). Specific RAAF bases were chosen to capture all types of active flying aircrew, with base visits timed to maximise aircrew availability (e.g. when squadron operational requirements were minimal). Only aircrew who were (a) active flying personnel, (b) medically fit, and (c) current on their respective aircraft type, were measured. While this tended to bias the sample towards younger aircrew, more senior officers in staff positions, although medically fit, were excluded because they were not current on aircraft type. The sample comprised 20% (97 of 482) cadet pilots and 80% (385 of 482) trained pilots, including instructor, fighter, bomber and transport pilots, and navigators. No information on the ethnic distribution of the sample was reported.

In the 1971 study, 17 body dimensions were physically measured using measurement protocols described in Hendy (1976). Body dimensions that were considered important determinants of cockpit fit were measured, including height, mass, and numerous girths, lengths, breadths and segmental heights. All subjects were measured in their underwear. Measuring equipment was routinely calibrated and included Salter 209 weighing scales for mass, fiberglass tailor's tapes for girths, small sliding calipers for head breadth, and several wall-mounted sliding anthropometers for height, lengths, and breadths (plus a custom-built anthropometry box for sitting heights). The anthropometry team comprised four anthropometrists. All measurements were made in centimetres to the nearest one decimal place and were handwritten onto hard copy survey cards. No data on the reliability or validity of these measurements were reported. Date of testing and date of birth were also recorded, with decimal age in years calculated. All hard copy data were manually entered on a Teletype and stored electronically on DEC (Digital Equipment Corporation) tape. Electronic data were then printed out to hard copy and checked for transcription errors against individual survey cards, with corrections made when data were incorrectly transcribed electronically or data deleted if the data were incorrectly transcribed on the survey cards. Data were also checked for within-subjects consistency [e.g. checked for whether height, sitting height, eye height (sitting), acromial height (sitting) and elbow rest height (sitting) maintained rank order], with anomalous data identified and all data for that subject subsequently deleted. Of the original sample, 4% (20 of 482) were excluded following data checking.

2.1.2 2005 Survey

In the 2005 study, 255 RAAF aircrew (9 females and 246 males) aged 19–56 years were measured as part of the ADAPT project – a large three-dimensional (3D) anthropometric survey of RAAF aircrew and the potential recruit population 18 to 30 years old (ADAPT project, unpublished data). Using the same subject inclusion criteria as in the 1971 study, a non-stratified sample of RAAF aircrew was selected from five RAAF bases (Amberley, Edinburgh, Pearce, Richmond and Williamtown), with base selection and the timing of base visits as per the 1971 study. (Note, only characteristics of the male aircrew are described here because female aircrew were excluded from the statistical analysis). The vast majority (88% or 216 of 246) of the aircrew were born in either Australia or New Zealand, with 7% (17 of 246) born in the UK, 2% (6 of 246) in the US, 2% (4 of 246) in Europe (other than the UK), and 1% (3 of 246) in other countries. The aim of the 2005 study was to gather anthropometric data on RAAF aircrew and a sample of the Australian population eligible for recruitment as RAAF aircrew to inform the design of clothing, protective equipment and cockpits. Numerous digital measurements (e.g. girths, lengths and breadths) and several physical measurements (e.g. height, mass, sitting height and buttock-knee length) were made on each subject, using procedures described in Olds et al. (2004 a,b). In addition, to determine the validity of the digital measurements, at least two other randomly selected dimensions (e.g. girths, lengths or breadths) were physically measured on each subject using International Society for the Advancement of Kinanthropometry (ISAK, 2001) protocols.

After having reviewed the information pack and provided written informed consent, each subject completed a computerised demographic and health questionnaire. Subjects then changed into form-fitting underwear and a swimming cap, in an effort to improve the accuracy of landmark location and to produce a better quality 3D image. All anthropometrists were accredited at Level 2 or higher by ISAK and demonstrated acceptable measurement reliability and validity (Gore et al., 1996). Height, mass, sitting height and buttock-knee length, as well as several other randomly selected dimensions, were physically measured in duplicate in centimetres to the nearest one decimal place, except for mass, which was measured in kilograms to two decimal places. Measuring equipment included a Leicester Height Measure portable stadiometer for height and sitting height (including a custom-built anthropometry box), Tanita System HD-332 digital weighing scales for mass, Lufkin W606PM steel tapes for girths, Siber-Hegner GPM anthropometers for lengths and large breadths, and customised Mitutoyo bone calipers for small breadths. The intra-tester technical error of measurement for the anthropometrists was 0.1% for height, 0.1% for mass, and 0.4% for all other physical measurements. The intra-class correlation coefficients ranged from 0.97 to 1.00. The intra-tester technical errors of measurement were well within acceptable limits as outlined by ISAK (Gore et al., 1996).

Twenty-three surface anatomical landmarks were then located via palpation and marked using double-sided adhesive stickers and small triangular blocks of balsa wood (see Figure 1). Once the subjects were landmarked they were ushered by their anthropometrist into the *Vitus Smart* 3D whole-body scanner (*Human Solutions*, Kaiserslautern, Germany) without being viewed by another individual (to maintain privacy). Subjects then stepped-up onto the raised platform inside the 3D scanner and were positioned into a standard scanning pose (Olds et al., 2004b). The standard scanning pose requires subjects to stand with head in the Frankfort

plane (ISAK, 2001); shoulders relaxed; arms slightly abducted; elbows slightly flexed; palms facing towards the body, with fingers extended and together and thumbs pointing forward; and, feet approximately hip width apart. With the curtains drawn, subjects were instructed to hold their breath (at end-tidal expiration) for the duration of the 10 second scan. The *Vitus Smart* whole body scanner captures a 3D image of the human body by passing Class 1 red laser light over its surface, and using a series of cameras, records the reflected light. The body is then represented as a "point cloud" on a computer, which is sewn together to create a "digital statue" (Figure 2).

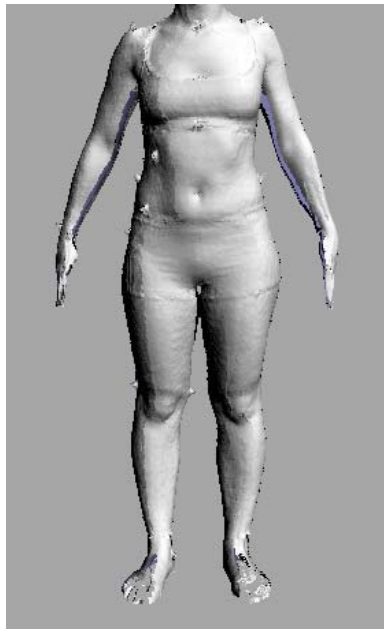*Figure 1:   Subject with landmarks placed on key anatomical points*

Figure 2:   Laser scan of subject

All 3D scan files were converted using *ScanWorX Editor* v2.8 (*Human Solutions*, Kaiserslautern, Germany) and *PlyTool* v1.4 (*Headus*, Perth, WA, Australia). *DigiSize* v2.3 (*Cyberware*, Monterey, CA, USA) measurement extraction software was then used to identify the Cartesian co-ordinates corresponding to 43 key landmarks (23 of which were physically landmarked). These Cartesian coordinates, along with height, mass and sex information, were exported as a text file. Using the co-ordinates of some of the landmarks, 18 point-to-point lengths and breadths were calculated. These digital measurements were then imported into *Excel*.

The gaps in the scans were filled using *CySlice* v3.4 (*Headus*, Perth, WA, Australia) measurement extraction software, and a number of measurements then extracted and exported as a comma-separated file. These comma-separated files were imported into *Excel* and combined with the other digital, physical and demographic data. Girth, length and breadth measurements are highly reliable (95% Limits of Agreement <1%; Daniell, 2007) and valid (95% Limits of Agreement <3%; Daniell, 2007) when compared to physical measurements taken by experienced (criterion) anthropometrists. (Note, reliability and validity data are only reported here for digital girths, lengths and breadths, as only these types of measurements were compared to the 1971 data as part of this study).

2.2 Comparable Anthropometric Dimensions

Comparison of the measured body dimensions and testing protocols from the 1971 and 2005 studies revealed that only nine body dimensions were comparable (i.e. directly measured in both studies) and suitable for comparison.

Table 1 lists the nine comparable body dimensions, identifies whether or not the 1971 and 2005 protocols were identical, and for non-identical protocols, describes the protocol differences. While the remaining eight body dimensions measured in 1971 were not directly measured in 2005, consideration was given to whether or not they could be confidently estimated from existing digital and physical data. These eight body dimensions were excluded from further analysis because their protocols required (a) body positions different to those that the subjects were scanned in, or (b) compression of body tissue which is not possible to estimate from the scans.

Table 1 Comparison of the measured body dimensions and measurement protocols from the 1971 and 2005 studies.

Measurement	1971	2005		1971 and 2005 protocols identical?	Difference in protocols
	Physical	Physical	Digital		
Height	●	●		no	In 2005, the stretch method was used, and in 1971, the non-stretch method was used
Mass	●	●		yes	
Sitting height	●	●		no	In 2005, the stretch method was used, and in 1971, the non-stretch method was used
Buttock-knee length	●	●		yes	
Chest girth	●		●	yes	
Waist girth	●	○	●	no	In 2005, waist girth was taken at narrowest point between the 10th rib and iliac crest, and in 1971, it was taken at the umbilicus level
Hip girth	●	○	●	yes	
Head girth	●	○	●	yes	
Head breadth	●		●	yes	

The "●" symbol indicates the measurements for which data were available for the entire sample (or the majority of the sample), and the "○" symbol indicates the measurements for which only limited data were available (the "○" identified measurements were only occasionally measured, with the data used to determine the validity of the digital measurements).

2.3 Data Cleaning and Treatment

Raw data were available for both the 1971 and 2005 studies. However, before secular changes in body dimensions could be calculated, it was necessary to clean the data and apply primary data treatment procedures to try to correct for known differences between the studies. Figure 3 shows the five steps taken to clean and treat the data prior to calculating secular changes. Step 1 involved data cleaning and comprised several parts. First, all female data (4% or 9 of 255) in the 2005 dataset were excluded, because the 1971 dataset comprised only anthropometric data on male RAAF aircrew. Second, all data on males aged <18 years and >40 years (5% or 35 of 708) were excluded. Third, all raw data were checked for anomalies by running range checks, with anomalous data identified if it fell more than four standard deviations (SDs) away from the respective study x dimension mean. In addition, scatterplots relating mass, sitting height, buttock-knee length, chest girth, waist girth, and hip girth to height, as well as chest girth to waist girth and waist girth to hip girth, were visually inspected for anomalies. Anomalous digital data were re-measured, checked and corrected where appropriate, with anomalous physical data deleted.

Steps 2 and 3 were implemented to try to correct for any known differences between the two studies in an effort to compare "like" measurements. Because all body dimensions in 1971 were measured using physical anthropometry, and body dimensions in 2005 were measured using a mix of digital and physical anthropometry, it was necessary to correct for differences between digital and physical measurements prior to secular analysis (Step 2). Digital data were available for five body dimensions – chest girth, waist girth, hip girth, head girth, and head breadth (Table 1). Correction of digital data was conducted in two parts. First, both digital and physical data, collected on the same set of individuals, were gathered for each body dimension; and second, a range of digital-to-physical prediction equations were generated, with physical measurements estimated using the best-fit prediction equations. However, differences in the availability of both digital and physical data meant that different datasets were needed to generate individual prediction equations.

For waist girth, hip girth, and head girth, both digital and physical data were available on approximately 140 males (both RAAF and general population) measured as part of the 2005 study. Available data varied somewhat for each body dimension (range 131–143). These datasets were retained for the digital-to-physical prediction for these three dimensions.
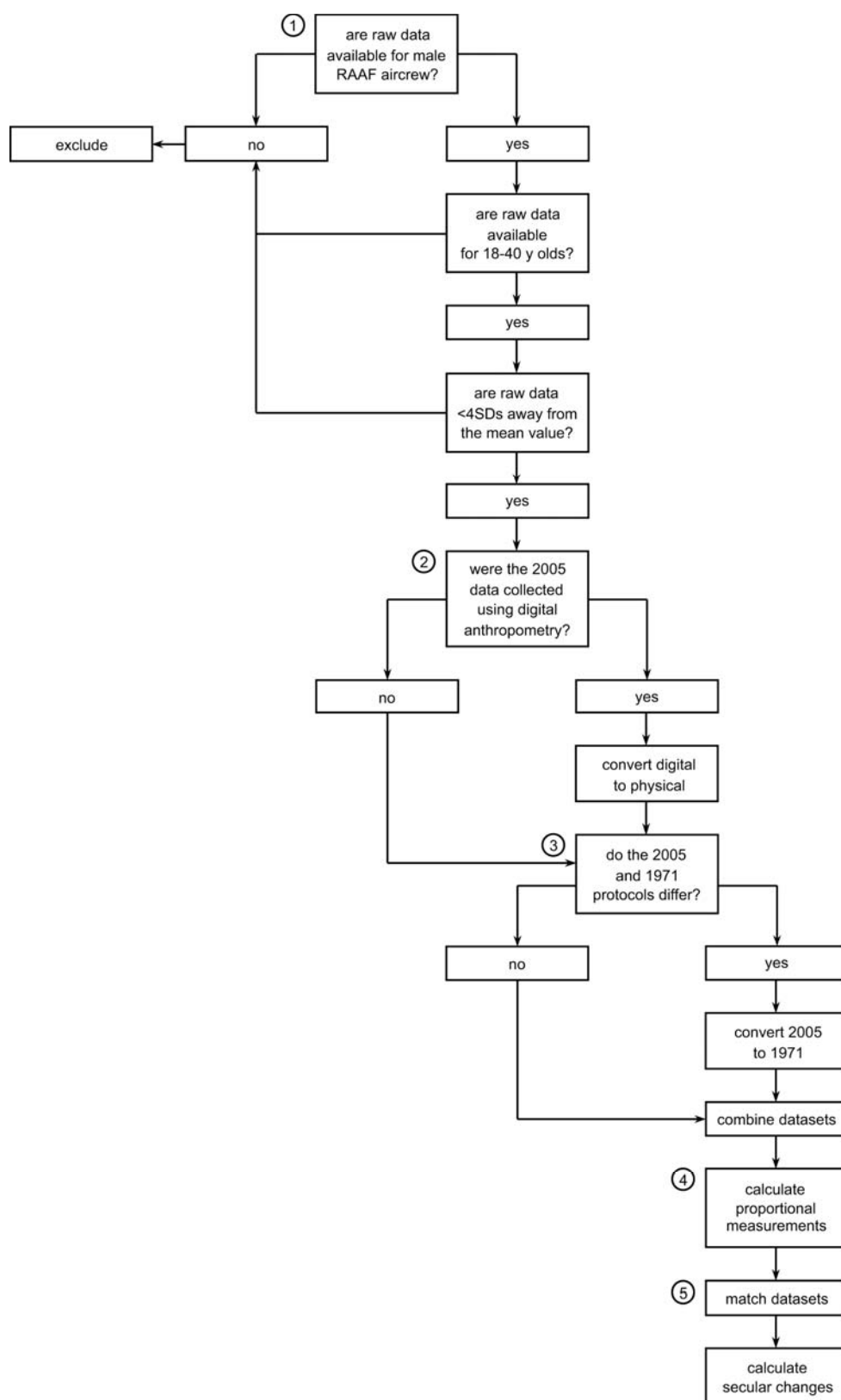
*Figure 3:   Flow chart showing the steps (1–5) to clean and treat the data prior to calculating the
secular changes*

In order to generate digital-to-physical prediction equations for chest girth and head breadth, both digital and physical data were collected on a convenience sample of 18–30 year old males ($n = 30$) who were eligible for recruitment as RAAF aircrew (e.g. adults who have completed the Higher School Certificate with passes in English, Mathematics and two other academic subjects). This convenience sample was recruited by word-of-mouth and email from the University of South Australia (UniSA) School of Health Sciences student pool and personal contacts (e.g. friends, family and work colleagues). All subjects were fully informed of the measurement procedures and their rights as volunteers, and all gave signed informed consent. UniSA's Human Research Ethics Committee approved all measurement procedures. It should be noted that the sample was limited to 30 subjects because of the measurement load, as approximately 1 h per subject was required to complete all digital and physical measurements. Furthermore, relative to a larger sample, a small sample will not bias the estimate of the effect (the regression coefficient), provided that the range in the predictor and response variables is not restricted. However, a small sample will reduce the confidence in the estimate of the effect.

Using the aforementioned datasets, separate linear and second-order polynomial models relating digital measurements (the predictor variable) to physical measurements (the response variable) were generated for each dimension. The coefficient of determination (r^2) was used as the criterion for goodness of fit. Linear models were retained as the best-fitting models in all instances. All linear models were highly significant ($p < 0.0001$), with the goodness of fit very high to almost perfect (median $r^2 = 0.92$; range 0.76–0.96) and the standard errors small (median standard error of estimate = 1.8%; range 1.1%–2.1%).

In Step 3 (Figure 3), corrections were made for body dimensions that were measured using different protocols, namely height, sitting height and waist girth (Table 1). Corrections for protocol differences were made using the same strategy as in Step 2; that is, physical data measured using both the 1971 and 2005 protocols, collected on the same set of individuals, were gathered for each body dimension, and a range of 2005 protocol-to-1971 protocol prediction equations were generated, with 1971 protocol measurements estimated using the best-fit prediction equations. As in Step 2, 2005 protocol-to-1971 protocol prediction equations were generated using the convenience sample of 18–30 year old males ($n = 30$) who were physically measured for height, sitting height and waist girth using both the 1971 and 2005 protocols. Separate linear and second-order polynomial models relating 2005 protocol measurements (the predictor variable) to 1971 protocol measurements (the response variable) were generated for each dimension, with linear models retained as the best-fitting models in all instances. All linear models were highly significant ($p < 0.0001$), with the goodness of fit almost perfect (median $r^2 = 0.996$; range 0.961–0.998) and the standard errors small (median standard error of estimate = 0.4%; range 0.2%–2.5%).

Following corrections for differences between digital and physical measurements and between measurement protocols, the 1971 and 2005 datasets were combined, with four proportional measurements subsequently derived (Figure 3, Step 4). The four proportional measurements were body mass index (BMI), sitting height:height ratio, chest:waist ratio and waist:hip ratio. Initial analysis of the combined dataset revealed that the 1971 sample was typically younger than the 2005 sample (27.0 y ± 5.1 y vs. 30.2 y ± 5.3 y, respectively). Further analysis revealed (as expected) age-related changes in the size of body dimensions throughout

early adulthood (Figure 4). Figure 4 shows that the size of lengths, breadths and heights (representing bone) remains relatively stable in 18–40 year old males (Figure 4; top panel), whereas mass and trunk girths (representing muscle and adipose tissue) change quite considerably with age, by as much as 15% in the case of mass (Figure 4; middle panel), and as a consequence, mass and trunk girth derived proportional measurements also change considerably (Figure 4; bottom panel). Given that the two samples were different in age, and with obvious age-related changes in the size of body dimensions, the two samples were age-matched prior to secular analysis to try to control for age-related differences in size (Figure 3, Step 5). Using a propensity score estimated by logistic regression (Rosenbaum and Rubin, 1983), each subject in the 2005 sample ($n = 220$) was matched one-for-one for decimal age with a subject from the 1971 study, using a greedy matching procedure (Gu and Rosenbuam, 1993). This dataset will be referred to as the "age-matched" dataset, in contradistinction to the "complete" dataset which refers to the combined dataset of all 18–40 year old male RAAF aircrew from 1971 ($n = 462$) and 2005 ($n = 220$). Furthermore, to determine whether the secular changes in body dimensions were independent of changes in overall body size, the two samples were also matched for age, height, mass and BMI using the greedy matching procedure, with subjects from 2005 ($n = 190$) matched one-for-one with a subject from 1971. This dataset will be referred to as the "age- and size-matched" dataset.
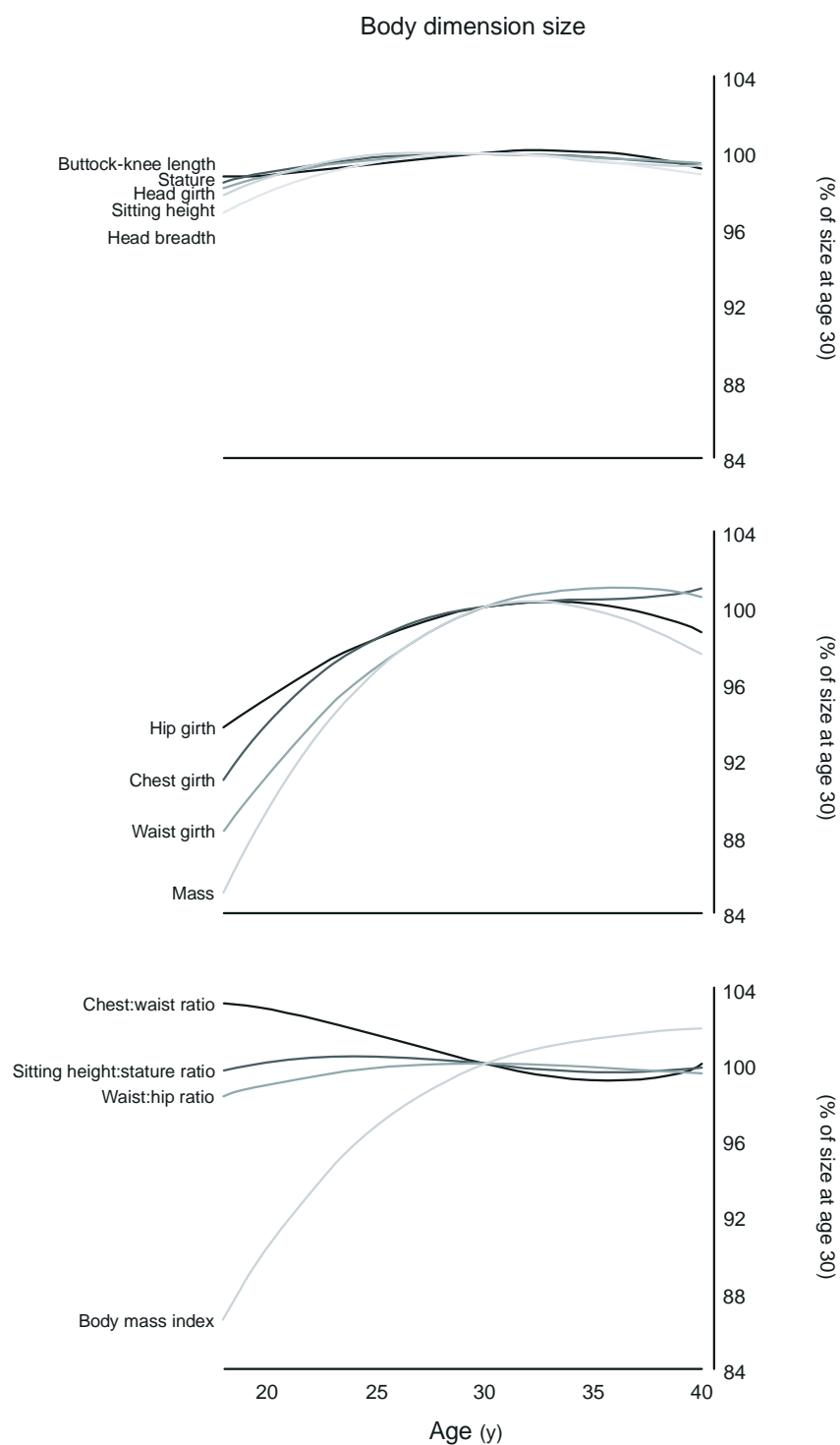
Figure 4: *The age-related changes in the size of body dimensions of 18–40 year old male RAAF aircrew. Body dimensions are represented as a percentage of values at age 30 (30 = 100%), with values greater than 100 indicating larger-sized dimensions and values less than 100 smaller-sized dimensions. Data are cross-sectional and are from the combined dataset (n = 669).*

2.4 Statistical Analysis

Changes in means and distributional changes between 1971 and 2005 were calculated for each body dimension using the age-matched dataset, with changes in means also calculated using the age- and size-matched dataset. Changes in means and their corresponding 95% confidence intervals (CI) were calculated to estimate the likelihood of the true change. Levene's test was used to examine equality of variance between groups, with the unpaired *t*-test used to examine equality of means for groups with equal variances and Aspin-Welch unequal variance *t*-test used for groups with unequal variances. Changes in means were expressed as both absolute and relative changes. An absolute change was calculated as the difference in means (2005 mean minus 1971 mean) divided by 3.4 (to express the change as a rate of change per decade), and a relative change was calculated as the difference in means expressed as a percentage of the corresponding 1971 mean value divided by 3.4. Positive changes indicate secular increases in mean values, and negative changes secular declines. The 95% CI for an absolute change was calculated as the absolute change ± 1.96 times the standard error of difference divided by 3.4. The 95% CI for a relative change was calculated by taking the 95% upper and lower confident limits for an absolute change and expressing them as a percentage of the corresponding 1971 mean value. The magnitude of an absolute change was quantified by calculating the standardised effect size (ES), defined as the difference in means divided by the pooled standard deviation (Cohen, 1988). The 95% CI of the true effect was calculated using the method outlined in Hopkins (2007). A modification of Cohen's guidelines for qualitative interpretation of the magnitude of effect sizes was used, with effect sizes of 0.2, 0.6 and 1.2 used as thresholds for small, moderate and large (Hopkins, 2002a). The likelihood that the true effect was worthwhile (i.e. greater than the smallest change) was also calculated, and the chances were qualitatively interpreted (Hopkins, 2002b). Secular changes in the prevalence of obesity were estimated using the American College of Sports Medicine's (2006) recommended cut-offs for BMI, waist girth and waist:hip ratio for obesity (adult males only) at >30 $kg.m^{-2}$, >102 cm and ≥ 0.95, respectively. Changes in the prevalence of obesity were determined using chi-square analyses, with the criterion for significance set at 0.05.

Distributional changes were examined broadly and specifically. First, secular changes in variability of body dimensions were examined by calculating the ratio of coefficients of variation (CV), by dividing the 2005 CV by the 1971 CV. The 95% CI of the true ratio was calculated using a maximum-likelihood technique (Verrill and Johnson, 2007). Ratios >1.1 indicated secular increases in variability, ratios <0.9 indicated secular declines in variability, and ratios between 0.9 and 1.1 were considered trivial. Second, distributional changes were also examined by visual inspection of a modified mean-difference plot, where the percentage differences between groups (expressed as relative changes per decade) at various percentile ranks (range 1–99) were plotted against the percentile ranks.

3. Results

In the complete dataset, the 1971 and 2005 samples were different in age (difference in means ± 95% CI: 3.15 y ± 0.84 y, ES moderate), but following age-matching, the two samples were similar in age (0.04 y ± 0.97 y, ES trivial). In the age-matched dataset, the changes between 1971 and 2005 were generally small, both for absolute and proportional dimensions (Table 2). For absolute dimensions, there were small increases in mass (secular change ± 95% CI: 1.99% ± 0.80% per decade), height (0.41% ± 0.19% per decade), buttock-knee length (0.44% ± 0.29% per decade), waist girth (0.83% ± 0.53% per decade), sitting height (0.28% ± 0.22% per decade) and hip girth (0.43% ± 0.33% per decade). There were also small increases in two proportional dimensions – BMI (1.14% ± 0.68% per decade) and waist:hip ratio (0.50% ± 0.33% per decade). The chances of small increases in these absolute and proportional dimensions were ≥70%. In contrast, there was a small decline for head girth (-0.39% ± 0.13% per decade).

Figure 5 shows the bivariate distribution of height and mass for male RAAF aircrew from 1971 (grey ellipse) and 2005 (black ellipse). Shown are the 90% density ellipses (i.e. the ellipses containing 90% of all individuals from the 1971 and 2005 age-matched samples). Notice that while there is considerable overlap between the 1971 and 2005 ellipses, the 2005 ellipse is displaced further towards the top and right of the figure relative to the 1971 ellipse, highlighting that 2005 male RAAF aircrew are taller and heavier than their 1971 counterparts. Notice also that the ellipses are similar in size, highlighting that the two groups, at least in terms of height and mass, are similarly variable (see also Table 2).

Following age- and size-matching, the two samples were similar in age (difference in means ± 95% CI: 0.47 y ± 1.02 y, ES trivial), height (0.45 cm ± 1.21 cm, ES trivial), mass (1.54 kg ± 2.10 kg, ES trivial) and BMI (0.34 kg.m^{-2} ± 0.57 kg.m^{-2}, ES trivial). When matched for age and overall body size, all but one of the secular changes were trivial, with the chances of small changes ≤32%. Therefore, the small increases (not including height, mass and BMI) observed in the age-matched dataset (Table 2) were not independent of secular changes in overall body size. However, the decline in head girth was independent of secular changes in overall body size (secular change ± 95% CI: -0.52% ± 0.13% per decade, ES moderate).

Variability in the 1971 and 2005 samples, as estimated by the ratio of the CVs (Table 2), tended to be similar, with the 2005 sample more variable for waist:hip ratio (ratio of CVs ± 95% CI: 1.23 ± 0.16) and less variable for head breadth (0.75 ± 0.12) and head girth (0.74 ± 0.10). Visual inspection of Figure 6 provides more specific information as to where in the distribution the secular changes have occurred. There has been little distributional change for most of the absolute (Figure 6, top and middle panels) and proportional (Figure 6, bottom panel) dimensions, with changes similar (difference <1% per decade) at the low (<10th), middle (40–60th) and high (>90th) percentiles. However, the secular changes for mass, BMI and waist:hip ratio have not been so uniform. For mass, the largest increases have occurred at the low percentiles (secular increase ~2.4–4.9% per decade), and to a lesser extent at the high percentiles (secular increase ~1.6-3.0% per decade), with relatively smaller increases in the middle percentiles (secular increase ~1.6–2.2% per decade). A similar pattern of change was observed for BMI, with the largest increases occurring at the low and high percentiles. For waist:hip ratio, the largest increases occurred at the high percentiles, indicating that the

secular increase in variability evidenced by the ratio of CVs was a skewed change (one tail of the distribution) rather than a uniform change (both tails). Furthermore, the prevalence of obesity significantly increased over the 34-year period by 1.2% per decade (from 3.2% to 7.4%, $\chi^2 = 5.7$, $p = 0.02$) according to BMI, or by 1.9% per decade (from 2.3% to 8.8%, $\chi^2 = 19.1$, $p < 0.0001$) according to waist girth, or 3.2% per decade (from 5.9% to 16.9%, $\chi^2 = 21.9$, $p < 0.0001$) according to waist:hip ratio.
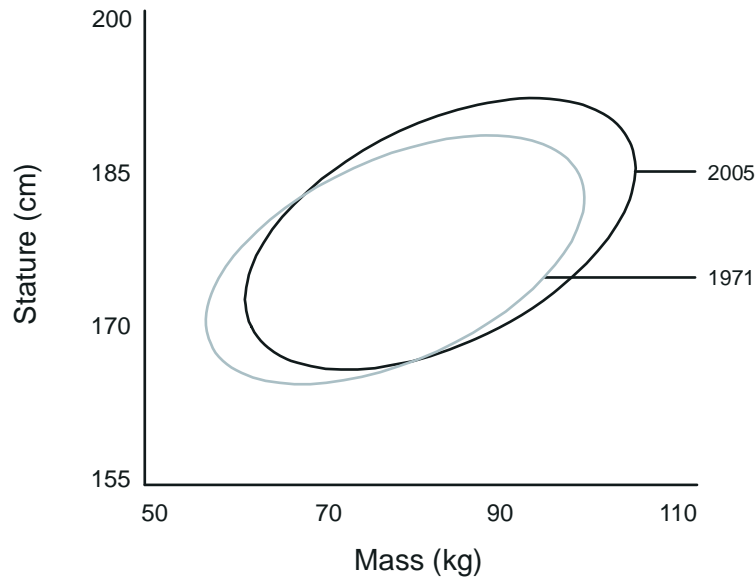

Figure 5:   *Bivariate distribution of height (cm) and mass (kg) for male RAAF aircrew from 1971 (grey ellipse) and 2005 (black ellipse). The ellipses are 90% density ellipses.*

Table 2 Changes in means and broad distributional changes in male RAAF aircrew between 1971 and 2005.

Body dimension	Year	n	Mean ± SD	Absolute change per decade ± 95% CI	Magnitude of effects			Ratio of CVs ± 95% CI
					Effect size ± 95% CI	Qualitative descriptor[a]	Chances of worthwhile effects (1971 to 2005)[b]	
Mass (kg)	2005	190	82.6 ± 10.9	1.54 ± 0.62	0.49 ± 0.20	small	100%: almost certainly larger	0.97 ± 0.13
	1971	220	77.4 ± 10.5					
Height (cm)	2005	190	180.2 ± 6.5	0.74 ± 0.36	0.41 ± 0.20	small	98%: very likely larger	1.09 ± 0.14
	1971	220	177.7 ± 5.9					
BMI (kg.m^{-2})	2005	190	25.4 ± 2.9	0.28 ± 0.17	0.33 ± 0.20	small	90%: likely larger	0.96 ± 0.13
	1971	220	24.5 ± 2.9					
Buttock-knee length (cm)	2005	134	62.1 ± 2.8	0.27 ± 0.18	0.33 ± 0.21	small	88%: likely larger	1.04 ± 0.14
	1971	220	61.2 ± 2.7					
Waist:hip ratio (%)	2005	177	89.1 ± 5.4	0.44 ± 0.29	0.31 ± 0.20	small	86%: likely larger	1.23 ± 0.16
	1971	220	87.6 ± 4.3					
Waist girth (cm)	2005	205	89.4 ± 8.4	0.72 ± 0.46	0.30 ± 0.19	small	85%: likely larger	1.02 ± 0.13
	1971	220	86.9 ± 8.0					
Sitting height (cm)	2005	189	93.1 ± 3.4	0.25 ± 0.19	0.25 ± 0.19	small	70%: possibly larger	0.99 ± 0.13
	1971	219	92.2 ± 3.4					
Hip girth (cm)	2005	205	100.5 ± 5.6	0.42 ± 0.32	0.25 ± 0.19	small	70%: possibly larger	0.94 ± 0.12
	1971	220	99.1 ± 5.9					
Chest girth (cm)	2005	167	99.9 ± 7.6	0.39 ± 0.43	0.18 ± 0.20	trivial	42%: possibly not larger	1.10 ± 0.15
	1971	220	98.6 ± 6.8					
Head breadth (cm)	2005	210	15.7 ± 0.4	0.01 ± 0.03	0.08 ± 0.19	trivial	10%: unlikely larger	0.75 ± 0.12
	1971	220	15.7 ± 0.5					
Sitting height:height ratio (%)	2005	189	51.7 ± 1.4	-0.06 ± 0.06	-0.14 ± 0.19	trivial	27%: possibly smaller	1.05 ± 0.13
	1971	219	51.9 ± 1.3					
Chest:waist ratio (%)	2005	167	112.8 ± 5.9	-0.31 ± 0.34	-0.18 ± 0.20	trivial	42%: possibly not smaller	1.06 ± 0.14
	1971	220	113.8 ± 5.7					
Head girth (cm)	2005	205	57.5 ± 1.2	-0.23 ± 0.07	-0.55 ± 0.19	small	100%: almost certainly smaller	0.74 ± 0.10
	1971	220	58.3 ± 1.6					

Note, positive values for absolute changes and effect sizes indicate secular increases in mean values and negative values secular declines. Ratio of CVs >1.1 indicate secular increases in variability and ratios <0.9 indicate secular declines in variability. SD = standard deviation. 95% CI = 95% confidence interval.
[a]Criteria for magnitude: <0.2 = trivial; 0.2-0.6 = small; 0.6-1.2 = moderate; >1.2 = large. Note, the negative scale also applied (e.g. -0.2 to -0.6 is small).
[b]Thresholds for assigning qualitative terms to chances of worthwhile effects were as follows: <1% = almost certainly not; <5% = very unlikely; <25% = unlikely; <50% = possibly not; >50% = possibly; >75% = likely; >95% = very likely; >99% = almost certainly
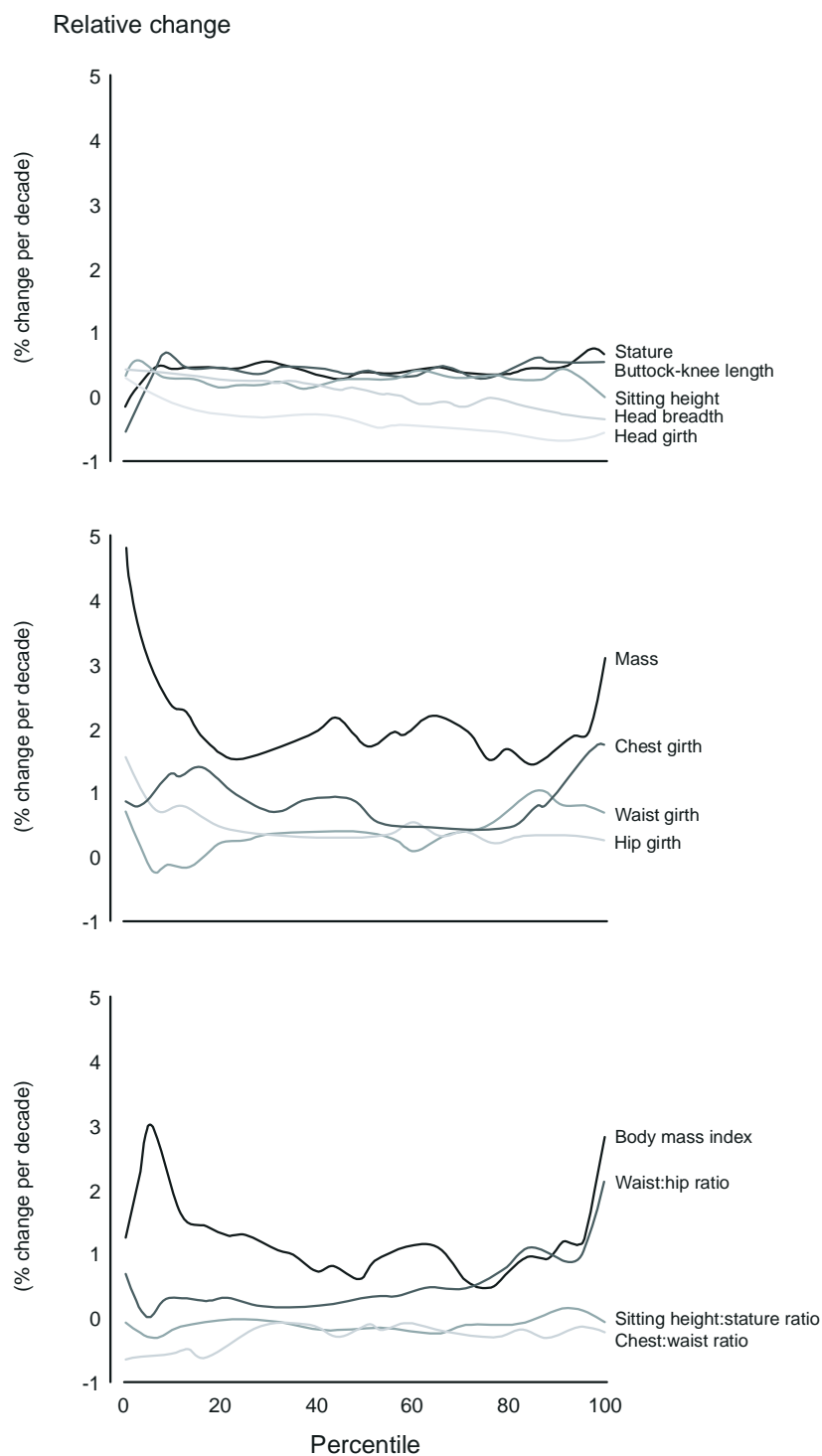
Relative change

Figure 6: *Distributional changes in body dimensions of RAAF aircrew between 1971 and 2005. The vertical axis shows the relative changes (% change per decade) at various percentile ranks (range 1–99), with positive values indicating secular increases and negative values secular declines. The horizontal axis shows the percentile ranks.*

4. Discussion

The main findings from this study are that there have small secular increases in several absolute and proportional body dimensions, and a small secular decline in head girth, in age-matched male RAAF aircrew between 1971 and 2005. These changes however, except that for head girth, were not independent of secular changes in overall body size. While sample variability has typically remained stable over time, the secular changes were not always uniform across the distribution.

4.1 Methodological Considerations

This study is the first to quantify secular changes in body dimensions of RAAF aircrew. While a number of studies have examined secular changes in body dimensions of overseas military personnel, few have quantified secular changes in such a broad range of body dimensions and over such a long period of time. While secular changes were estimated over a 34-year period in this study, they were only estimated between two time-points, and it is important to remember that not all secular changes are linear. A clear strength of this study is that it used a systematic strategy to quantify secular changes. Furthermore, matching the samples by age meant that age-related differences that may have influenced the secular changes were controlled for, and matching the samples by age, height, mass and BMI meant that secular changes in body dimensions could be examined independent of changes in age and overall body size.

Ideally, secular comparisons should be made between samples that are randomly selected. In this study however, secular comparisons were made between two samples that were selected by convenience. Both in 1971 and 2005, the aim was to measure as many active flying aircrew, who were medically fit and current on their aircraft type, as possible. To do this, aircrew were sampled from several RAAF bases that were specifically chosen to capture all pilot types. Despite the convenience sampling, the two samples represent a reasonable proportion of the RAAF, with approximately 54% (486 of 900) and 19% (246 of 1300) of total active flying aircrew sampled in 1971 and 2005 respectively (Dr. Bhupi Singh, Institute of Aviation Medicine, personal communication, August, 2008). Furthermore, the ethnic distribution of the 2005 sample is remarkably similar to that of the rest of the RAAF (Roy Morgan Research, 1999). Without any evidence of secular changes in the ethnic distribution of the RAAF, the estimated secular changes in body dimensions reported in this study will not be systematically biased.

Hendy (1976) reported that in the 1971 study, the mass and trunk girths of cadet pilots were significantly smaller than those of trained pilots, with lengths, breadths and heights similarly-sized. Analysis of the 1971 dataset reveals that cadet pilots were younger than trained pilots (21.3 y ± 2.3 y vs. 28.5 y ± 5.5 y, respectively; difference in means ± 95% CI: 7.19 y ± 0.73 y, ES large), and with greater age-related changes in mass and trunk girths in early adulthood than in lengths, breadths and heights (see Figure 2), these size-related differences between cadet and trained pilots are likely to be the function of differences in age. However, this will not bias the estimate of the secular changes in body dimensions unless there are differences in the proportion of cadet and trained pilots and differences in age between the two samples.

There were no significant differences in the distribution of pilot types (cadets vs. trained pilots, χ^2 = 3.1, p = 0.08) and no differences in age (in either the age-matched or the age- and size-matched datasets) between the 1971 and 2005 samples.

Distributional changes can systematically bias secular changes in mean values. In this study, non-uniform changes were observed for mass, BMI and waist:hip ratio (see Figure 6), with changes in mean values artefactually inflated by secular increases in positive skew. In the age-matched dataset, secular changes in mass, BMI and waist:hip ratio were 14–71% larger when calculated using mean values (1.99%, 1.14% and 0.50% per decade, respectively) than when calculated using median values (1.74%, 0.66%, 0.32% per decade, respectively), nonetheless, the direction of change was consistent. Differences between secular changes calculated using mean and median values were much smaller for the remaining body dimensions.

4.2 Secular Comparisons Between the RAAF and General Population

There are few secular data available on body dimensions of Australian adults. All of the available secular data are for height and mass, as these variables have been routinely measured or estimated (self-reported) in large health and nutrition surveys of Australian adults over the past few decades, often to calculate BMI and to estimate the prevalence of overweight and obesity. Most of the recent studies examining secular changes in Australian adults have used self-reported height and mass data to demonstrate that there have been increases in the prevalence of overweight and obesity over the past couple of decades (Australian Bureau of Statistics, 2005; Australian Institute of Health and Welfare, 2003; Dal Grande et al., 2005). While secular changes estimated from self-reported data will not be biased, unless there are secular changes in the validity of the self-reports, self-reported height and mass do provide lower BMI values than measured height and mass (Niedhammer et al., 2000), and therefore should not be combined with measured data when estimating secular changes.

Using only measured height and mass data, Figure 7 shows the secular changes in height (top left), mass (middle left), BMI (bottom left), and estimates of the prevalence of overweight (top right) and obesity (bottom right) in male RAAF aircrew (black lines) and 25–44 year old urban Australian males (grey lines). Lowess curves (tension = 66) were used to estimate secular changes in Australian males, and the changes in RAAF aircrew were assumed to be linear. Secular data for height, mass and BMI were available for the period 1980–1995 and for prevalence estimates of overweight and obesity for the period 1980–2000. These data represent the best available comparative data.

Figure 7 shows that height has remained relatively stable (-0.1% per decade) and that there have been increases in mass (3.4% per decade) and BMI (3.6% per decade) in Australian males between 1980 and 1995. For mass and BMI, there was an initial decline from 1980 to 1983, and increases thereafter, with the rate of increase accelerating since 1989. While it is hard to know the exact time-related patterns of change in male RAAF aircrew (because there are only two time-points), and despite that secular changes in Australian males are relatively temporally limited, it appears that the secular increases in mass and BMI are much larger in Australian males than they are in male RAAF aircrew. A similar pattern emerges for secular changes in the prevalence of overweight and obesity. Between 1980 and 2000, the prevalence of

overweight and obesity in Australian males increased by 5.0% and 5.7% per decade, respectively. These secular increases are some 3–4.5 times greater than the increases observed in male RAAF aircrew. Without any evidence that these secular increases in Australia males have slowed in recent years (Australian Bureau of Statistics, 2005; Australian Institute of Health and Welfare, 2003; Dal Grande et al., 2005) it is possible that the secular differences between RAAF and Australian males are somewhat underestimated. It therefore appears that the secular changes in RAAF aircrew are similar in direction to changes in Australian males, but the magnitude of change, at least for mass, BMI and the prevalence of overweight and obesity, is smaller.

4.3 Explanation of Main Findings

Secular changes in adult height and mass are well documented (Cole, 2000; Hauspie et al., 1997; Roche, 1979). Secular increases in adult height have been observed in many countries over the past 100-150 years, and although the secular increase in height is continuing, it appears to have slowed (and stabilised in some countries) since about 1975 (Cole, 2000). While it is difficult to know whether the secular increase in height and mass of RAAF aircrew has slowed or stabilised in recent years, the 0.74 cm per decade increase between 1971 and 2005 is in line with global changes for that time (Cole, 2000; Hauspie et al., 1997). Numerous reasons for secular increases in height have been proposed, although the exact underlying causal mechanisms are unclear (Malina, 1979). It is likely that secular changes in body dimensions are largely due to the elimination of growth-inhibiting factors (Van Wieringen, 1986), which are mainly driven by changes in environmental conditions, nutrition and health care (Cole, 2000; Hauspie et al., 1997; Malina, 1979).

Assuming geometric similarity principles, human lengths, girths and breadths should change in proportion to height (Olds et al., 1995). Therefore, secular changes in lengths, girths, and breadths should be approximately proportional to secular changes in height, suggesting little secular change in overall body shape and proportions. However, there is some evidence which suggests that secular increases in height are largely due to increases in leg length (Himes, 1979; Tanner et al., 1982). As a consequence, sitting height:height ratios have fallen over time, signaling a secular change in body proportions. In this study, there were small, similarly sized secular increases in height, sitting height, buttock-knee length (upper leg length), waist girth and hip girth in age-matched individuals. In contrast, there was a small secular decline in head girth. While there was no secular change in sitting height:height ratio, there were small secular increases in BMI and waist:hip ratio, suggestive of a secular change in body shape. However, consistent with geometric similarity principles, these secular changes in body dimensions (except head girth) were proportional to secular increases in overall body size.
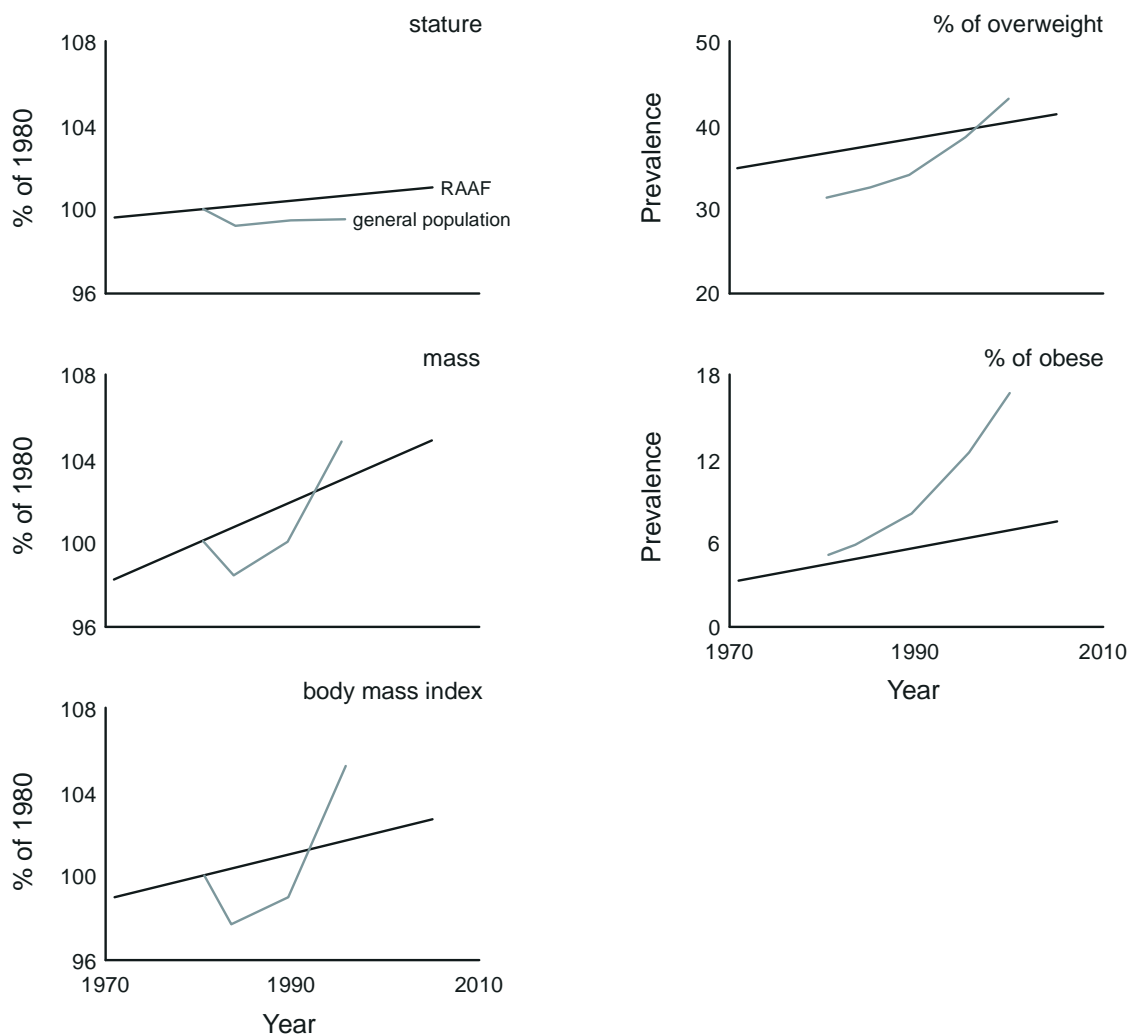
Figure 7: *Secular changes in height (top left), mass (middle left), body mass index (bottom left), and estimates of the prevalence of overweight (top right) and obesity (bottom right) in male RAAF aircrew (black lines) and 25–44 year old urban Australian males (grey lines). Lowess curves (tension = 66) were used to estimate secular changes in Australian males. Height, mass and body mass index are represented as a percentage of 1980 values. Prevalence rates were estimated using World Health Organisation (1998) adult cut-offs for body mass index of 25.0-29.99 kg.m^{-2} for overweight and ≥30 kg.m^{-2} for obesity. Secular data on Australian males are from National Heart Foundation of Australia (1981; 1984; 1990), Australian Bureau of Statistics (1997) and Cameron et al. (2003).*

The secular decline in head girth is difficult to explain. It is possible that head girths really have declined over time, although to our knowledge, there is no previous evidence of this. Declines in head girth are independent of changes in overall body size, which is not surprising given that head girth is only weakly-moderately related to height, mass and BMI. However, given that there is a strong cross-sectional relationship between head girth and head breadth ($r = 0.54$), a concomitant secular change in head breadth would be expected, although a trivial secular increase in head breadth was actually observed. An examination of head girths from

the 2005 dataset revealed that the differences in means and CVs between male RAAF aircrew and male general population were trivial, suggesting that the head girths of RAAF aircrew in 2005 were not atypical. A similar comparison using the 1971 dataset was not possible.

Secular changes in mass, like the changes in height, are also continuing, but in contrast, increases in mass appear to have accelerated in recent decades (Cole, 2000). This recent time-related acceleration in mass is the likely function of increases in fatness, in particular, greater increases in the high percentiles (the obese end) of the distribution (Cole, 2000; Flegal and Troiano, 2000). In this study, while there was a small secular increase in the mass of RAAF aircrew, equivalent to 1.54 kg per decade, the secular increase was not uniform, with greater increases in light and heavy aircrew than in those of average mass.

But is there any evidence that RAAF aircrew are fatter now than in the past? While analysis of secular changes in direct measurements of fat mass was not possible in this study, analysis of secular changes in commonly used indicators of fat mass may provide some clues. BMI, waist girth, and waist:hip ratio have been commonly used to indicate fatness and obesity. For example, the World Health Organisation (1998) recommends adult cut-offs for BMI and waist girth for obesity, and the American College of Sports Medicine (2006) recommends adult cut-offs for BMI, waist girth and waist:hip ratio. Historically, BMI has been used to indicate fatness, although it has been criticised as it is only indicates heaviness, and does not discriminate between fat mass and fat-free mass. Recently however, waist girth and waist:hip ratio have gained in popularity as they are thought to be more closely related to the distribution of body fat (e.g. abdominal visceral fat) and in the case of waist girth, may be a better predictor of cardiovascular disease risk than BMI in adults (Zhu et al., 2002). Cross-sectionally in healthy, sedentary adults, BMI and waist girth are almost perfectly correlated with one another and with fat mass, and are very highly correlated with abdominal visceral fat (Bouchard, 2007). Using data on 1,288 black and white men and women from the Quebec Family Study and the HERITAGE Family Study, Bouchard (2007) reported age-corrected correlations between BMI and fat mass (mean $r = 0.94$; range among study x sex x ethnic groups: 0.90–0.96) and computer tomography assessed abdominal visceral fat ($r = 0.72$; range 0.69–0.77), with waist girth as equally well correlated with fat mass ($r = 0.92$; range 0.86-0.96) and abdominal visceral fat ($r = 0.77$; range 0.69-0.83). The correlation between BMI and waist girth was 0.93 (range 0.87-0.95). [Note, the correlation between BMI and waist girth in this study was very high ($r = 0.88$)]. Given the strength of these cross-sectional relationships, it is not surprising that similar sized secular increases were observed (when age-matched) for BMI and waist girth in this study. These secular changes in BMI and waist girth therefore suggest that there have been secular increases in fat mass and abdominal visceral fat of male RAAF aircrew over the 1971–2005 period, with increases greater at the low, and most alarmingly at the high, percentiles of the distribution (Figure 6).

Secular increases in fatness are generally considered to be the result of behavioural changes such as excessive energy intake relative to expenditure, reduced energy expenditure, and reduced vigorous physical activity (Kuczmarski et al., 1994; Prentice and Jebb, 1995). Though there are few reliable secular data on energy intake and energy expenditure in Australian adults, largely due to variability in sampling and methodology, several context-specific snapshots do exist. Using data from two national nutrition surveys, Cook et al. (2001) reported that energy intakes in Australian adults increased by 4% between 1983 and 1995. There have

also been declines in Australian adults' use of active transport (e.g. cycling and walking). Between 1960 and 1990 the percentage of travel using active transport in Australia declined from 10% to 5% (Kenworthy and Laube, 1999), and between 1996 and 2000, the number of adults walking or cycling to work declined by 22% and 54%, respectively (Australian Bureau of Statistics, 2003). These behavioral changes are most likely mediated by broad social changes, which have resulted in an environment that is becoming "toxic for exercise". The increased use of sedentary technologies and labor-saving devices, a changing family profile, a breakdown of local communities, and a shift towards suburbanisation have all been implicated (French et al., 2001; Olds and Harten, 2001). One area where quantifiable data are available on Australian adults is the increased use of sedentary technologies. Australian Bureau of Statistics (2003) figures show that between the 1960s and 1990s, television ownership per head of population doubled. Some (but not all) adult studies have found that as the amount of television watched increases, physical activity levels decrease and obesity increases (Cameron et al., 2003; Gortmaker et al., 1996). Motor transport has also played a major role in reducing physical activity. Between 1947 and 1992, the number of persons per non-commercial private car in Australia decreased sixfold from 12.5 to 2.0 (Australian Bureau of Statistics, 2001). Between 1960 and 1990, annual per capita driving distance in Australia doubled (Kenworthy and Laube, 1999). The increase in car ownership and driving distance means that adults will less often rely on active forms of transport to travel to and from work. Furthermore, while behavioral and environmental changes are likely to be largely responsible, the distributional changes in fatness and mass are also likely to be due to gene-environment interactions, where genetic differences lead to a differential responsiveness to the environment (Hill et al., 2003). Irrespective of the underlying causal mechanisms, it is the secular changes in body dimensions which are the primary focus in this study.

4.4 Implications for the RAAF

The results of this study have numerous implications for the RAAF, especially implications for health and human-equipment fit. Consider first the effect of secular increases in fatness on the health of RAAF aircrew. In adults, increased fatness (operationalised as BMI) has been linked with morbidity and mortality from cardiovascular disease and all-causes (Flegal et al., 2005; Gelber et al., 2007; McGee, 2004; World Health Organisation, 1998). While studies have consistently found that obesity (BMI >30 kg.m^{-2}) is associated with increased mortality relative to normal weight (BMI 18-25 kg.m^{-2}), numerous studies (but not all) have found that overweight (BMI 25-30 kg.m^{-2}) is not associated with increased mortality (Flegal et al., 2005; McGee, 2004). The results of this study suggest that there have been secular increases in fatness and obesity of RAAF aircrew over the past few decades, and from a health-related perspective, it is the secular increases in obesity which are of greatest concern, as mortality risk appears to only be heightened in obese individuals. Irrespective of which metric is used to indicate obesity, this study suggests that there has been somewhere between a 2–3.5-fold increase in obesity prevalence in male RAAF aircrew since 1971. While it is tempting to speculate that the 2005 RAAF aircrew, because they are typically fatter and more obese, are at greater risk of mortality than the 1971 aircrew, Australian and US evidence suggests that secular increases in fatness and obesity have coincided with secular declines in several cardiovascular disease risk factors (e.g. cholesterol, blood pressure and smoking) (Bennett and Magnus, 1994; Gregg et al., 2005). These changes have also coincided with increases in lipid-lowering and anti-hypertensive medication use, particularly among obese persons. So while

today's RAAF aircrew are typically fatter and more obese, and obese individuals are at an increased risk of morbidity and mortality, they are likely to be relatively less at risk than their peers from the past because the impact of obesity on mortality has apparently decreased over time.

From a health surveillance point of view, it is also important to consider that in male RAAF aircrew, the secular increases in waist girth and waist:hip ratio were not independent of increases in overall body size. When matched for age and overall body size, the increases in waist girth and waist:hip ratio were trivial, with the age-matched increases reduced by 83% and 52%, respectively. These data suggest that changes in BMI when taken alone, are a perfectly adequate surrogate (relative to waist girth and waist:hip ratio) of secular changes in fatness. Nonetheless, reinforcing the recommendations of others (e.g. Bouchard, 2007), multiple indicators (including both direct and indirect) should be used when monitoring the status of, and changes in, fatness.

Secular increases in body dimensions of RAAF aircrew also have implications for the acquisition of new aircraft, the upgrading of existing aircraft, and the design and sizing of the clothing and protective equipment worn by aircrew. Because of the enormous cost of acquiring military aircraft, RAAF aircraft typically have a lifespan of several decades. For example, the F-111 has been in service for 35 years and the Caribou for 44 years. In addition, due to the lengthy development periods for military aircraft, the anthropometric data used to guide the design of an aircraft may be well over a decade old when the aircraft finally enters service. Given the lengthy development period and operational life of a typical aircraft, a pilot may end up flying an aircraft that was designed using anthropometric data that is over 50 years old. In light of the secular increases in body dimensions of RAAF aircrew, the pool of available aircrew that can fly an aircraft may shrink over the life of the aircraft. Ideally, the body dimensions of current aircrew, along with an estimate of the size of the aircrew at the end of the aircraft's planned service life (through secular analysis), should be taken into account when acquiring new aircraft or upgrading existing aircraft to maximise the number of available aircrew. Furthermore, given the secular changes in body dimensions of RAAF aircrew reported in this study, the sizing and design of clothing and equipment, such as g-suits (worn by fast jet pilots), flying suits and helmets, worn by aircrew should be reviewed periodically to ensure the clothing and equipment will fit optimally and a sufficient range of sizes are available to fit all aircrew.

5. Concluding Remarks

In summary, there has been a small secular increase in several absolute and proportional body dimensions of male RAAF aircrew over the period 1971-2005, although these increases were not independent of overall changes in body size. However, there was a small secular change in head girth that was independent of overall body size. Furthermore, secular changes were not always uniform across the distribution. These secular changes in body dimensions have implications for clothing and equipment design and sizing, health, and human-machine fit and underscore the need for regular anthropometric surveys of RAAF aircrew. To ensure data is available on the size of current aircrew the Institute of Aviation Medicine will measure aircrew on a regular basis.

6. Acknowledgements

7. References

- American College of Sports Medicine. 2006. ACSM's guidelines for exercise testing and prescription (7th ed). Baltimore, MD: Lippincott Williams & Wilkins.

- Australian Bureau of Statistics. 1997. National Nutrition Survey: selected highlights 1995. Canberra: Australian Government Publishing Service.

- Australian Bureau of Statistics. 2001. 2001 year book Australia. Canberra, ACT: Australian Bureau of Statistics.

- Australian Bureau of Statistics. 2003. 2003 year book Australia. Canberra, ACT: Australian Bureau of Statistics.

- Australian Bureau of Statistics. 2005. National Health Survey 2004-2005: summary of results. Canberra: Australian Government Publishing Service.

- Australian Institute of Health and Welfare. 2003. Are all Australians gaining weight? Differentials in overweight and obesity among adults 1989-90 to 2001. Canberra: Australian Institute of Health and Welfare.

- Bennett SA, and Magnus P. 1994. Trends in cardiovascular risk factors in Australia: results from the National Heart Foundation's Risk Factor Prevalence Study, 1980-1989. Med J Aust 161: 519-527.

- Bouchard C. 2007. BMI, fat mass, abdominal adiposity and visceral fat: where is the 'beef'? Int J Obes Relat Metab Disord 31: 1552-1553.

- Burnsides D, Boehmer M, and Robinette K. 2001. 3-D landmark detection and identification in the CAESAR project. In: Proceedings of the Third International Conference on 3-D Digital Imaging and Modeling, May, Quebec City, Canada, 2007. p 393-398.

- Cameron AJ, Welborn TA, Zimmet PZ, Dunstand DW, Owen N, Salmon J, Dalton M, Jolley D, and Shaw JE. 2003. Overweight and obesity in Australia: the 1999-2000 Australian diabetes, obesity and lifestyle study (AusDiab). Med J Aust 178: 427-432.

- Cohen J. 1988. Statistical power analysis for the behavioral sciences (2nd ed). New Jersey: Lawrence Erlbaum.

- Cole TJ. 2000. Secular trends in growth. Proc Nutr Soc 59: 317-324.

- Cook T, Rutishauser I, and Seelig M. 2001. Comparable data on food and nutrient intake and physical measurements from the 1983, 1985 and 1995 national nutrition surveys. Canberra: Commonwealth Department of Health and Aged Care.

- Daniell N. 2007. A comparison of the accuracy of the Vitus Smart® and Hamamatsu BodyLine® 3D whole-body scanners. In: Marfell-Jones M, Olds T, editors. Kinanthropometry X. London: Routledge. p 39-54.

- Dal Grande E, Gill T, Taylor AW, Chittleborough C, and Carter P. 2005. Obesity in South Australian adults – prevalence, projections and generational assessment over 13 years. Aust NZ J Public Health 29: 343-348.

- Flegal KM, Graubard BI, Williamson DF, and Gail MH. 2005. Excess deaths associated with underweight, overweight, and obesity. JAMA 293: 1861-1867.

- Flegal KM, and Troiano RP. 2000. Changes in the distribution of body mass index of adults and children in the US population. Int J Obes Relat Metab Disord 24: 807-818.

- French SA, Story M, and Jeffery RW. 2001. Environmental influences on eating and physical activity. Annu Rev Public Health 22: 309-335.

- Gelber RP, Kurth T, Manson JE, Buring JE, and Gaziano JM. 2007. Body mass index and mortality in men: evaluating the shape of the association. Int J Obes Relat Metab Disord 31: 1240-1247.

- Gore C, Norton K, Olds T, Whittingham N, Birchall K, Clough M, Dickerson B, and Downie L. 1996. Accreditation in anthropometry: an Australian model. In Norton K, Olds T, editors. Anthropometrica. Sydney: University of New South Wales Press. p 395-411.

- Gortmaker SL, Must A, Sobol AM, Peterson K, Colditz GA, and Dietz WH. 1996. Television viewing as a cause of increasing obesity among children in the United States, 1986-1990. Arch Pediatr Adolesc Med 150: 356-362.

- Gregg EW, Cheng YJ, Cadwell BL, Imperatore G, Williams DE, Flegal KM, Narayan KM, and Williamson DF. 2005. Secular trends in cardiovascular disease risk factors according to body mass index in US adults. JAMA 293: 1868-1874.

- Greiner TM, and Gordon CC. 1992. Secular trends of 22 body dimensions in four racial/cultural groups of American males. Am J Hum Biol 4: 235-246.

- Gu XS, and Rosenbaum PR. 1993. Comparison of multivariate matching methods: structures, distances and algorithms. J Comput Graph Stat 2: 405-420.

- Hauspie RC, Vercauteren M, and Susanne C. 1997. Secular changes in growth and maturation: an update. Acta Paediatr (Supplement) 423: 20-27.

- Hendy KC. 1976. Anthropometric survey of R.A.A.F pilots, 1971. Canberra: Commonwealth of Australia.

- Hill JO, Wyatt HR, Reed GW, and Peters JC. 2003. Obesity and the environment: where do we go from here? Science 299: 853-855.

- Himes JH. 1979. Secular changes in body proportions and composition. In Roche AF, editor. Secular trends in human growth, maturation, and development (Serial no. 179, Monographs of the Society for Research in Child Development). Chicago, IL: University of Chicago Press. p 28-58.

- Hopkins WG. 2002a. A scale of magnitudes for effect statistics. (Available: sportsci.org/resource/stats/effectmag.html).

- Hopkins WG. 2002b. Probabilities of clinical or practical significance. Sportscience 6 (Available: sportsci.org/jour/0201/wghprob.htm).

- Hopkins WG. 2007. A spreadsheet for deriving a confidence interval, mechanistic inference and clinical inference from a p value. Sportscience 11 (Available: sportsci.org/2007/wghinf.htm).

- International Society for the Advancement of Kinanthropometry. 2001. International standards for anthropometric assessment. Potchefstroom, RSA: International Society for the Advancement of Kinanthropometry.

- Kenworthy J, and Laube F. 1999. An international sourcebook of automobile dependence in cities, 1960-1990. Boulder, CO: University Press of Colorado.

- Knapik JJ, Sharp MA, Darakjy S, Jones SB, Hauret KG, and Jones BH. 2006. Temporal changes in the physical fitness of US Army recruits. Sports Med 36: 613-634.

- Kuczmarski RJ, Flegal KM, Campbell SM, and Johnson CL. 1991. Increasing prevalence of overweight among US adults: the National Health and Nutrition Examination Surveys. 1960 to 1991. JAMA 272: 205-211.

- Malina RM. 1979. Secular changes in size and maturity: Causes and effects. In Roche AF, editor. Secular trends in human growth, maturation, and development (Serial no. 179, Monographs of the Society for Research in Child Development). Chicago, IL: University of Chicago Press. p 59-120.

- Malina RM, and Little BB. 2008. Physical activity: the present in the context of the past. Am J Hum Biol 20: 373-391.

- McGee DL. 2004. Body mass index and mortality: a meta-analysis based on person-level data from twenty-six observational studies. Ann Epidemiol 15: 87-97.

- National Heart Foundation of Australia. 1981. Risk factor prevalence study: report no. 1. Canberra: National Heart Foundation of Australia.

- National Heart Foundation of Australia. 1985. Risk factor prevalence study: report no. 2. Canberra: National Heart Foundation of Australia.

- National Heart Foundation of Australia. 1990. Risk factor prevalence study: report no. 3. Canberra: National Heart Foundation of Australia.

- Niedhammer I, Bugel I, Bonenfant S, Goldberg M, and Leclerc A. 2000. Validity of self-reported weight and height in the French GAZEL cohort Int J Obes Relat Metab Disord 24: 1111-1118.

- Olds TS, and Harten NR. 2001. One hundred years of growth: The evolution of height, mass, and body composition in Australian children, 1899-1999. Hum Biol 73: 727-738.

- Olds T, Norton K, Van Ly S, and Lowe L. 1995. Similarity systems in anthropometry. In Norton K, Olds T, editors. Anthropometrica. Sydney: University of New South Wales Press. p 121-145.

- Olds T, Tomkinson G, Rogers M, Kupke T, Lowe L, Daniell N, and Honey F. 2004a. 3D anthropometry: ADAPT procedures manual. Adelaide: University of South Australia.

- Olds T, Tomkinson G, Rogers M, Kupke T, Lowe L, and Daniell N. 2004b. 3D anthropometry: ADAPT landmarking manual. Adelaide: University of South Australia.

- Prentice AM, and Jebb SA. 1995. Obesity in Britain: gluttony or sloth? BMJ, 311, 437-439.

- Roche, AF. 1979. Secular trends in stature, weight, and maturation. In Roche AF, editor. Secular trends in human growth, maturation, and development (Serial no. 179, Monographs of the Society for Research in Child Development). Chicago, IL: University of Chicago Press. p 3-27.

- Rosenbaum PR, and Rubin DB. 1983. The central role of the propensity score in observational studies for causal effects. Biometrika 70: 41-55.

- Roy Morgan Research. 1999. Australian Defence Force 1999 census: final report. Melbourne: Roy Morgan Research.

- Sharp MA, Patton JF, Knapik JJ, Hauret K, Mello RP, Ito M, and Frykman PN. 2002. Comparison of the physical fitness of men and women entering the U.S. Army: 1978-1998. Med Sci Sports Exerc 34: 356-363.

- Soar N. 1999. An examination of the secular trend in Australian male stature as seen in the military data. Perspect Hum Biol 4: 157-166.

- Tanner JM, Hayashi T, Preece MA, and Cameron N. 1982. Increase in length of leg relative to trunk in Japanese children and adults from 1957 to 1977: comparison with British and with Japanese Americans. Ann Hum Biol 9: 411-423.

- Van Wieringen JC. 1986. Secular growth changes. In Falkner F, Tanner JM, editors. Human growth – Volume 3 (2nd ed). New York: Plenum Press. p 307-331.

- Verrill SP, and Johnson RA. 2007. Confidence bounds and hypothesis tests for normal distribution coefficients of variation (Research paper 638). Madison, WI: USDA Forest Products Laboratory.

- World Health Organisation. 1998. Obesity: preventing and managing the global epidemic. Geneva: World Health Organisation.

- Zhu S, Wang Z, Heshka S, Heo M, Faith MS, and Heymsfield SB. 2002. Waist circumference and obesity-associated risk factors among whites in the third National Health and Nutrition Examination Survey: clinical action thresholds. Am J Clin Nutr 76: 743-749

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION DOCUMENT CONTROL DATA		1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

| 2. TITLE

Body Size Changes of Royal Australian Air Force Aircrew: 1971 - 2005 | 3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION)

Document   (U)
Title   (U)
Abstract   (U) |

| 4. AUTHOR(S)

Grant Tomkinson, Adam Clark and Peter Blanchonette | 5. CORPORATE AUTHOR

DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend Victoria 3207 Australia |

6a. DSTO NUMBER DSTO-TR-2339	6b. AR NUMBER AR-014-612	6c. TYPE OF REPORT Technical Report	7. DOCUMENT DATE August 2009

8. FILE NUMBER 2009/1026603	9. TASK NUMBER DMO 07/077	10. TASK SPONSOR DGCLOSPO	11. NO. OF PAGES 28	12. NO. OF REFERENCES 57

13. URL OF ELECTRONIC VERSION http://dsto.defence.gov.au/corporate/reports/DSTO-TR-2339.pdf	14. RELEASE AUTHORITY Chief, Air Operations Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111

16. DELIBERATE ANNOUNCEMENT

No Limitations

17. CITATION IN OTHER DOCUMENTS	Yes

18. DSTO RESEARCH LIBRARY THESAURUS http://web-vic.dsto.defence.gov.au/workareas/library/resources/dsto_thesaurus.shtml

anthropometry, aircrews, human machine interfaces

19. ABSTRACT
The aim of this study was to quantify the secular changes in body dimensions of Royal Australian Air Force (RAAF) aircrew between 1971 and 2005. Small secular increases were observed for most body dimensions, including height, mass and body mass indices, although a small decline was observed for head girth. These secular changes (except for head girth) were not independent of changes in overall body size. In addition, secular changes were not always uniform across the distribution. Secular increases in body dimensions of RAAF aircrew have implications for health, clothing design and sizing, and human-equipment fit.